C. Chen et al. (Eds.)

doi:10.3233/978-1-61499-779-5-925

Construction and Application of Functional Requirement Model of the Urban Intelligent Lighting Appliance (UILA) Based on the Users' Need

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Abstract. The multi-functional Urban intelligent lighting Appliance(UILA) has become the important technology terminal to realize the construction of our smart city for future. By far, one of the most urgent problems which need to be solved is the way to apply those new functions to the UILAs effectively according to the users' need.This article takes Shanghai(China) as an example, analyzing and summarizing the functional demands of the future UILA from perspectives of functions, environment, aesthetics and energy-efficiency in the way of experts interview and bibliographic retrieval. By applying the theory of Kansei Engineering, we collect the data of the urban-dwellers' perceptual demand for the UILA's functions in different areas through questionnaires, specify the intention of the needing of the UILA's functions by combing Kansei engineering design with factor analysis, and set up the model to evaluate this application.The result of the research will provide the strong evidence for the relevant UILA design and make a big contribution to the future smart city construction.

Keywords. Urban intelligent lighting appliance(UILA), User demand, Functional intention, Design evaluation, Smart city

Introduction

The concept of "smart city" was initially proposed by IBM in 2008. By far, over 1200 cities in the world have joined in smart city construction [1]. China started the smart city construction in 2012. As the earliest smart city construction in China, Shanghai has formed the basic framework of being a smart city characterized by digitalization, networking and intelligentization after carrying out the 2011-2013 action plan of "smart city" construction. Smart city construction is an effective means to improve the core competitiveness of cities in the future, and it is seen as a development trend for cities in the future world.

By taking urban street lamps as the carrier and integrating multi-function hardware such as solar photovoltaic, LED lighting, micro nodes, video monitors, multimedia screens, information interaction screens, card readers, loudspeakers, and sensors, UILA

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aim to carry out localized development and share of government affairs, people's livelihood, commerce, culture, tourism, and traffic in smart cities on the basis of the information application system platform. Through hardware implantation, software superposition, and application expansion, organic integration of CityPad is to be realized and extensively applied to different scenes of cities, such as business areas, communities, parks, scenic spots and roadway lighting. Thus, it becomes a physical information system of smart cities.

Multi-functional UILA looks set to be an important technical terminal of smart city construction in the future. Via the multidimensional social collaborative design, existing street lamps will be upgraded, and the information perception network that covers sufficiently wide scope will be established soon, thus realizing the basic network platform of internet in smart cities, facilitating ultimate function and goal of improving people's life quality, and playing a key role in urban management, process and image. Therefore, it is of great importance to study the functional requirement of intelligent lighting devices in different areas of cities [2].

1. Design theories related to user needs

An important part of the "people-oriented" design idea is the study on user needs which refers to some physiological or psychological need of users in accordance with their specific enviornment [3]. According to Maslow's Hierarchy of Needs, user needs can be divided into the availability requirement from the phsyical and functional hierarchy, the applicability and validity requirement from the physiological and psychological hierarchy, and the human needs from the subjective feeling hierarchy [4].

Currently, design theories related to user needs in the product design and development process mainly include Kansei Engineering, emotional design, and engineering aesthetics [5]. Kansei Engineering is to carry out tests for physiological inforamtion of users such as their brain wave, electromyographic signal, sight trace, expression capture, and behavior record by means of application engineering technology, so as to quantify emotional needs of users, establish the relationship model between users' need space and product characteristic space, and provide scientific basis for product design and development. Emotional design is a design theory based on users' emotional needs, and it is to carry out design and development from the instinct, behaviors and reflection of users' emotion. Engineering aesthetics is a new discipline proposed by Liu Y L [6] who introduced ergonomics to the aesthetics field and advocated to use systematic and scientific engieneering and technology ways for aesthetic design and evaluation.

2. Design of the functional requirement research scheme of urban intelligent lighting devices based on user needs

Through research ways related to user needs, the functional requirement intention of intelligent lighting devices in different areas of cities will be determined in four steps, and the functional evaluation correlation model of intelligent lighting devices will be established [7].

2.1. Main functions of urban intelligent lighting devices in the future will be determined via expert interviews

Through the literature review of intelligent functional requirement of urban street lamps in the future, plus the interview with 39 experts from 18 enterprises specialized in R&D, production and manufacturing of intelligent lighting such as Moma Industry Design Group, Huawei Technologies Co., Ltd., and China Telecom, main functions of urban intelligent lighting devices in the future are summarized: photovoltaic system, LED lighting, intelligent sensing, micro node, rich-media ad, emergency call, city monitor system, charging pile, electronic signpost, weather monitoring, handy service for the public, and green conservation.

2.2. Questionnaire design about the functional requirement of intelligent lighting devices

Via literature review, it is found that urban functional zones are usually divided into the administration zone, residential mix zone, residential zone, greenbelt zone of scenic cities, central business zone, institute and college zone, high-tech zone, industrial zone, and suburbs. Different zones and 12 functions of cities are given with different numbres, and the semantic difference scale about the functional requirement of intelligent lighting devices in different zones of cities is established. The reliability and validity of the scale should be controlled in order to ensure the accuracy of the survey.

Table 1. Main functional requirements of urban intelligent lighting devices.

Number	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6**
Function	Photovoltaic system	LED lighting	Intelligent sensing	Micro node	Rich-media ad	Emergency call
Number	**Y7**	**Y8**	**Y9**	**Y10**	**Y11**	**Y12**
Function	City monitor system	Charging pile	Electronic signpost	Weather monitoring	Handy service for the public	Green conservation

2.3. Evaluation and analysis of functional requirements of intelligent lighting devices by users from different zones of cities

Through the questionnaire, evaluation of functional requirements of intelligent lighting devices in different zones of cities is provided by users, thereby obtaining the perceptual cognizance of functional requirements of intelligent lighting devices by users.

2.4. Establishing the functional requirement correlation model of different urban zones and intelligent lighting devices and make conclusions

Main functional requirements of different urban zones are determined, the corresponding relations between different urban zones and intelligent lighting devices are summarized, and functional requirement construction ways of urban intelligent lighting devices based on user needs are concluded.

3. Result

Due to the limited length of the paper, according to the research design plan, this paper focuses on the analysis of urban landscape green area, Central Business District and high-tech area.

3.1. High - tech area

The data were subjected to KMO dome test before factor analysis.P=0.776>0.5and sig.=0.000<0.05,the test results are in accordance with the analysis conditions.As shown in Table 2, the rotation component matrix is obtained by maximizing the orthogonal rotation of the initial component load matrix.It can be seen that the variables with high load on the first common factor are Y9, Y10, Y11, which are summarized as the interaction factor.Y6 is a high load on the second common factor, defined as safety factor.Y2, Y7 are the high load variables on the third common factor, defined as the lighting factor.Y12 is a high load on the fourth common factor, defined as greening factor. Which sums up the semantic core behind the 12 functional requirements and excavates the potential factors.

Table 2. High - tech area common factor data table.

Common factor	Sensual vocabulary	Factor load	Characteristic value	Variance contribution rate/%	Cumulative contribution rate/%
X11 (interaction factor)	Y9	.748	3.120	35.996	35.996
	Y10	.749			
	Y11	.879			
X12 (safety factor)	Y6	- .687	1.813	15.110	41.106
X13 (lighting factor)	Y2	.752	1.623	13.522	54.629
	Y7	.649			
X14 (greening factor)	Y12	.827	1.285	10.710	65.339

The component score coefficient matrix was obtained according to the Thomson regression method, the model of functional evaluation of UILA in the establishment of High - tech area is as follows:

Interaction factor $X11= 0.043Y1 - 0.018Y2 - 0.042Y3 - 0.173Y4 + 0.174Y5 + 0.136Y6 + 0.085Y7 + 0.183Y8 + 0.240Y9 + 0.240Y10 + 0.282Y11 + 0.050Y12$

Safety factor $X12= 0.285Y1 + 0.100Y2 + 0.328Y3 + 0.084Y4 + 0.242Y5 - 0.379Y6 - 0.295Y7 - 0.066Y8 + 0.173Y9 + 0.143Y10 - 0.035Y11 - 0.022Y12$

Lighting factor $X13= 0.186Y1 + 0.464Y2 + 0.182Y3 + 0.216Y4 + 0.111Y5 + 0.102Y6 + 0.400Y7 + 0.271Y8 - 0.102Y9 - 0.107Y10 + 0.063Y11 - 0.072Y12$

Greening factor $X14= -0.109Y1 - 0.238Y2 + 0.389Y3 + 0.050Y4 + 0.075Y5 + 0.149Y6 + 0.012Y7 + 0.161Y8 + 0.108Y9 - 0.238Y10 - 0.140Y11 + 0.643Y12$

3.2. Landscape green area

The data were subjected to KMO dome test before factor analysis. P=0.719>0.5 and sig.=0.000<0.05,the test results are in accordance with the analysis conditions.As shown in Table 3, the rotation component matrix is obtained by maximizing the orthogonal rotation of the initial component load matrix.It can be seen that the variables on the first common factor are Y6, Y7, Y8, Y9, Y11 According to its meaning summarized as service factor.Y2, Y10 is a high load on the second common factor, defined as the basis factor.Y1 is the third largest factor on the high load of the variable, defined as environmental factor.Y5, Y12 is a high load on the fourth common factor, defined as greening factor.Which sums up the semantic core behind the 12 functional requirements and excavates the potential factors.

Table 3. Landscape Greening Area Common Factor Data Sheet.

Common factor	Sensual vocabulary	Factor load	Characteristic value	Variance contribution rate/%	Cumulative contribution rate/%
X21 (service factor)	Y6	.645	3.127	31.060	31.060
	Y7	.677			
	Y8	.680			
	Y9	.878			
	Y11	.646			
X22 (basis factor)	Y2	.688	2.038	16.982	43.042
	Y10	-.667			
X23 (environmental factor)	Y1	.607	1.577	13.143	56.185
X24 (greening factor)	Y5	-.647	1.319	10.992	67.177
	Y12	.807			

The component score coefficient matrix was obtained according to the Thomson regression method, the model of functional evaluation of UILA in the establishment of landscape green area is as follows:

Service factor X21= 0.081Y1 + 0.036Y2 + 0.144Y3 + 0.178Y4 + 0.076Y5 + 0.206Y6+0.217Y7 + 0.217Y8 + 0.249Y9 + 0.094Y10 + 0.207Y11 + 0.059Y12

Basis factor X22= -0.242Y1 + 0.338Y2 + 0.172Y3+ 0.232Y4 + 0.214Y5 - 0.001Y6+0.155Y7 -0.172Y8 -0.136Y9 - 0.327Y10 - 0.055Y11 + 0.083Y12

Environmental factor X23= 0.385Y1 + 0.150Y2 + 0.243Y3 + 0.073Y4 + 0.025Y5 - 0.281Y6 + 0.107Y7 - 0.224Y8 + 0.081Y9 + 0.313Y10 - 0.319Y11 + 0.228Y12

Greening factor X24= -0.227Y1 + 0.256Y2 - 0.096Y3 - 0.218Y4 - 0.490Y5 + 0.018Y6 + 0.156Y7 + 0.150Y8 - 0.067Y9 + 0.059Y10 + 0.041Y11 + 0.536Y12

3.3. Central Business District

The data were subjected to KMO dome test before factor analysis.P=0.758>0.5and sig.=0.000<0.05,the test results are in accordance with the analysis conditions.As shown in Table 4, the rotation component matrix is obtained by maximizing the orthogonal rotation of the initial component load matrix.It can be seen that the variables with high load on the first common factor are Y9, Y11, which are summarized as the interaction factor.Y4 is a high load on the second common factor, defined as safety factor.Y6 are the high load variables on the third common factor, defined as the safety factor.Y12 is a high load on the fourth common factor, defined as greening factor. Which sums up the semantic core behind the 12 functional requirements and excavates the potential factors.

Table 4. Central Business District common factor data table.

Common factor	**Sensual vocabulary**	**Factor load**	**Characteristic value**	**Variance contribution rate/%**	**Cumulative contribution rate/%**
X31 (interaction factor)	Y9	.633	2.850	33.749	33.749
	Y11	.749			
X32 (network factor)	Y4	.611	1.715	14.289	28.038
X33 (safety factor)	Y6	.654	1.436	11.966	50.004
X34 (greening factor)	Y12	- .717	1.170	9.750	59.754

The component score coefficient matrix was obtained according to the Thomson regression method, the model of functional evaluation of UILA in the establishment of Central Business District is as follows:

Interaction factor = 0.204Y1 + 0.157Y2 + 0.137Y3 - 0.020Y4 + 0.208Y5 + 0.055Y6 + 0.138Y7 + 0.167Y8 + 0.222Y9 + 0.196Y10 + 0.263Y11 + 0.126Y12

Network factor = -0.237Y1 + 0.209Y2 + 0.326Y3 + 0.356Y4 + 0.249Y5 - 0.269Y6 + 0.189Y7 - 0.016Y8 - 0.093Y9 - 0.259Y10 - 0.054Y11 + 0.025Y12

Safety factor = 0.135Y1 + 0.074Y2 + 0.139Y3 + 0.133Y4 - 0.294Y5 + 0.455Y6 + 0.234Y7 + 0.360Y8 - 0.309Y9 - 0.164Y10 - 0.113Y11 + 0.149Y12

Greening factor = -0.032Y1 + 0.391Y2 - 0.275Y3 + 0.073Y4 - 0.041Y5 + 0.119Y6 + 0.402Y7 - 0.142Y8 - 0.076Y9 + 0.198Y10 + 0.038Y11 - 0.613Y12

3.4. Summary of functional requirements in different regions of the city

According to the analysis results to further summarize the functional requirements, which is related to the function of the region required functional elements, negative correlation function refers to the region does not need functional elements, as shown in Figure 1.

	High-tech area	Landscape greening area	Central Business District	industrial area	Administrative area	suburbs	Living mixed area	Residential area	Cultural and educational district
Positive correlation function		Y1		Y1	Y1	Y1		Y1	
	Y2	Y2		Y2	Y2	Y2			
					Y3	Y3	Y3	Y3	
			Y4	Y4	Y4		Y4	Y4	Y4
						Y5	Y5	Y5	
		Y6	Y6			Y6	Y6		Y6
	Y7	Y7		Y7	Y7				
		Y8		Y8	Y8			Y8	Y8
	Y9	Y9	Y9	Y9	Y9		Y9		
	Y10			Y10	Y10	Y10	Y10	Y10	Y10
	Y11	Y11	Y11	Y11			Y11	Y11	Y11
	Y12	Y12						Y12	
Negative correlation function	Y6	Y5 Y10	Y12			Y8			Y3

Figure 1. Summary of functional requirements in different regions of the city.

4. Conclusion

Through literature review and expert interviews, the functional zoning and functional requirement intention of urban intelligent lighting devices are determined. By making use of the user need related design theories, the quantized value of functional requirements of UILA in different zones is found. With the integration of factor analysis, the functional core and potential factors behind functional requirements are summarized, functional requirement for UILA in different urban zones is explored, and the functional evaluation correlation model of UILA is estbalished, thus providing vigorous basis and reference to the design and development of intelligent lighting devices, and helping designers to design UILA meeting user needs.

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